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ND 27

OFFICE OF SCIENTIFIC RESEARCH & DEVELOPMENT
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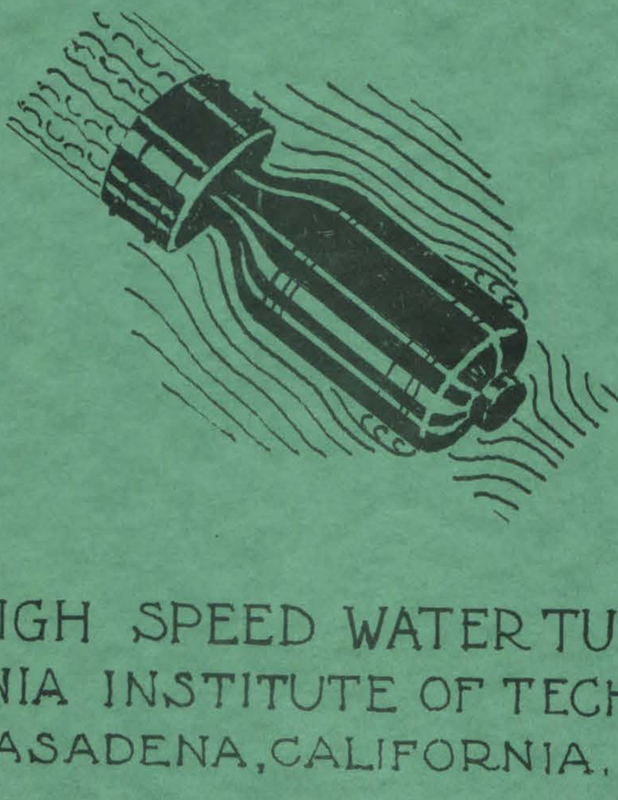
DIVISION SIX-SECTION 6.1

WATER TUNNEL TESTS
OF THE
3.5" ROTATING ROCKET



THE HIGH SPEED WATER TUNNEL
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA.

SECTION № 6.1-sr-207-1270
HML REP. № ND-27

COPY № 120

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WATER TUNNEL TESTS

OF THE

3.5" ROTATING ROCKET

BY

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OFFICIAL INVESTIGATOR

THE HIGH SPEED WATER TUNNEL
AT THE
CALIFORNIA INSTITUTE OF TECHNOLOGY
HYDRAULIC MACHINERY LABORATORY
PASADENA, CALIFORNIA

Section No. 6.1-sr-207-1270

HML Rep. No. ND-27

April 21, 1944

Report Prepared by

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Hydraulic Engineer

SUMMARY

This report covers tests of a 2" diameter model of the 3.5" Rotating Rocket. Five different designs of nose were tested and the drag, cross force, and moment coefficient curves determined. This projectile is unstable under static conditions, without rotation, except for yaw angles between - 1-1/2° and + 1-1/2° in which region a slight stabilizing moment was observed.

The drag coefficient varies from 0.28 at 0° yaw to 0.39 at 16° yaw and the cross force coefficient varies from zero at 0° yaw to 0.71 at 16° yaw. The moment coefficient curve, except for the region between - 1-1/2° and + 1-1/2° yaw, shows a destabilizing moment which reaches a maximum of + 0.081 at approximately 14° yaw.

A series of tests was made to determine the effect of asymmetry of the nose. The model was assembled so the axis of the nose made an angle of about 1-1/2° with the axis of the body. This is equivalent to the center of the tip of the prototype nose being offset 1/8" from the center line of the body. This rather large asymmetry of the nose produced so little change in the drag, cross force, and moment that it would appear to be negligible from the practical standpoint.

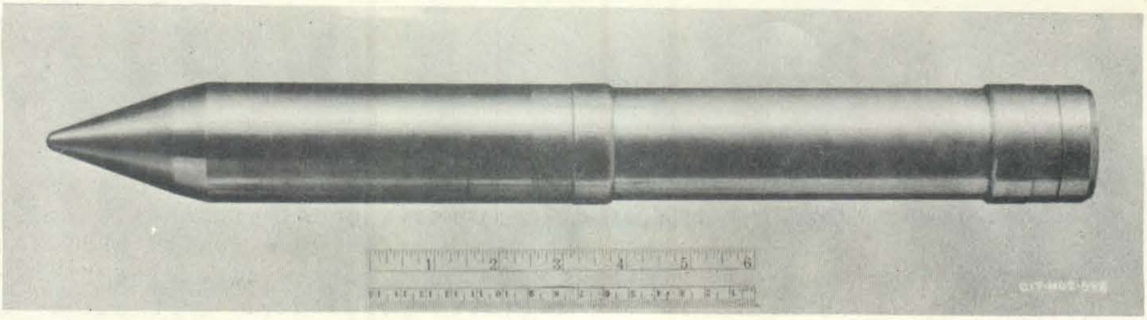


FIGURE 1

MODEL WITH NOSE NO. 48

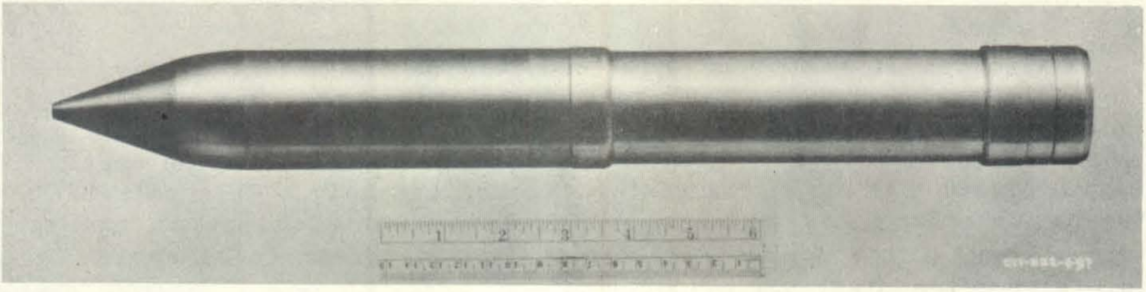


FIGURE 2

MODEL WITH NOSE NO. 51

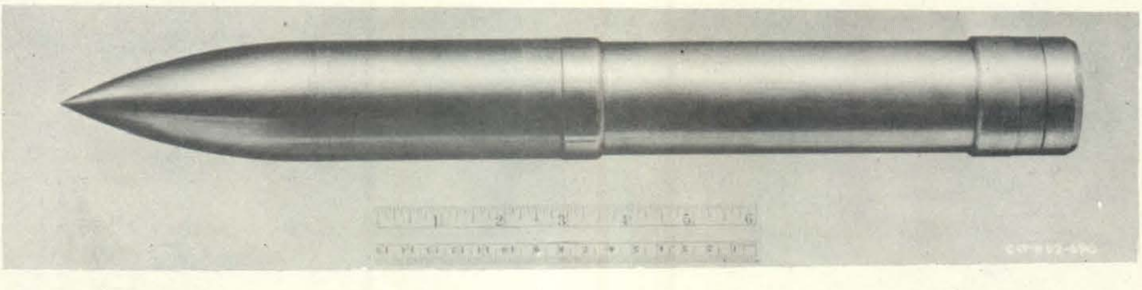


FIGURE 3

MODEL WITH NOSE NO. 50

WATER TUNNEL TESTS

OF THE

3.5" ROTATING ROCKET

GENERAL

This report covers tests of a 2" diameter model of the 3.5" Rotating Rocket, conducted at the Hydraulic Machinery Laboratory of the California Institute of Technology. This work was authorized by letter of January 31, 1944, from Dr. E. H. Colpitts, Chief of Section 6.1, NDRC, New York City.

The purpose of the tests was to determine the performance of various modifications of the original design of this rocket, the principal changes being in the type of nose used. The Water Tunnel tests supplied the required data for determining the drag, cross force, and moment, also the center-of-pressure eccentricity over a wide range of yaw angles. Preliminary reports of the test results were issued from time to time for use in the development of the final design.

Appendix A gives definitions of the terms used in this report, as well as a brief discussion of the required conditions for stability in a non-rotating projectile. This report deals only with static stability of a projectile without rotation.

DESCRIPTION OF PROTOTYPE AND MODEL

The photographs, Figures 1, 2, and 3 show the 2" diameter model with three different nose designs. The No. 54 nose design, which was finally adopted for this projectile, is not shown although it is very similar to the No. 51 nose. Outline drawings of all of the noses that were tested are shown in Figure 4. An outline drawing of the rocket with the final No. 54 nose is shown in Figure 5. These nose numbers are laboratory designations only and do not refer to the number used for the prototype.

The following physical data are given for this projectile (without propellent):

Length overall	24.875 inches
Maximum diameter	3.5 inches
Nose to center of gravity	11.0 inches
Mass	21.75 pounds
Velocity	760 ft/sec
Rotation	181 r. per sec
Transverse moment of inertia	7.25 lb ft^2
Polar moment of inertia	0.285 lb ft^2
Transverse radius of gyration	0.576 ft
Polar radius of gyration	0.117 ft

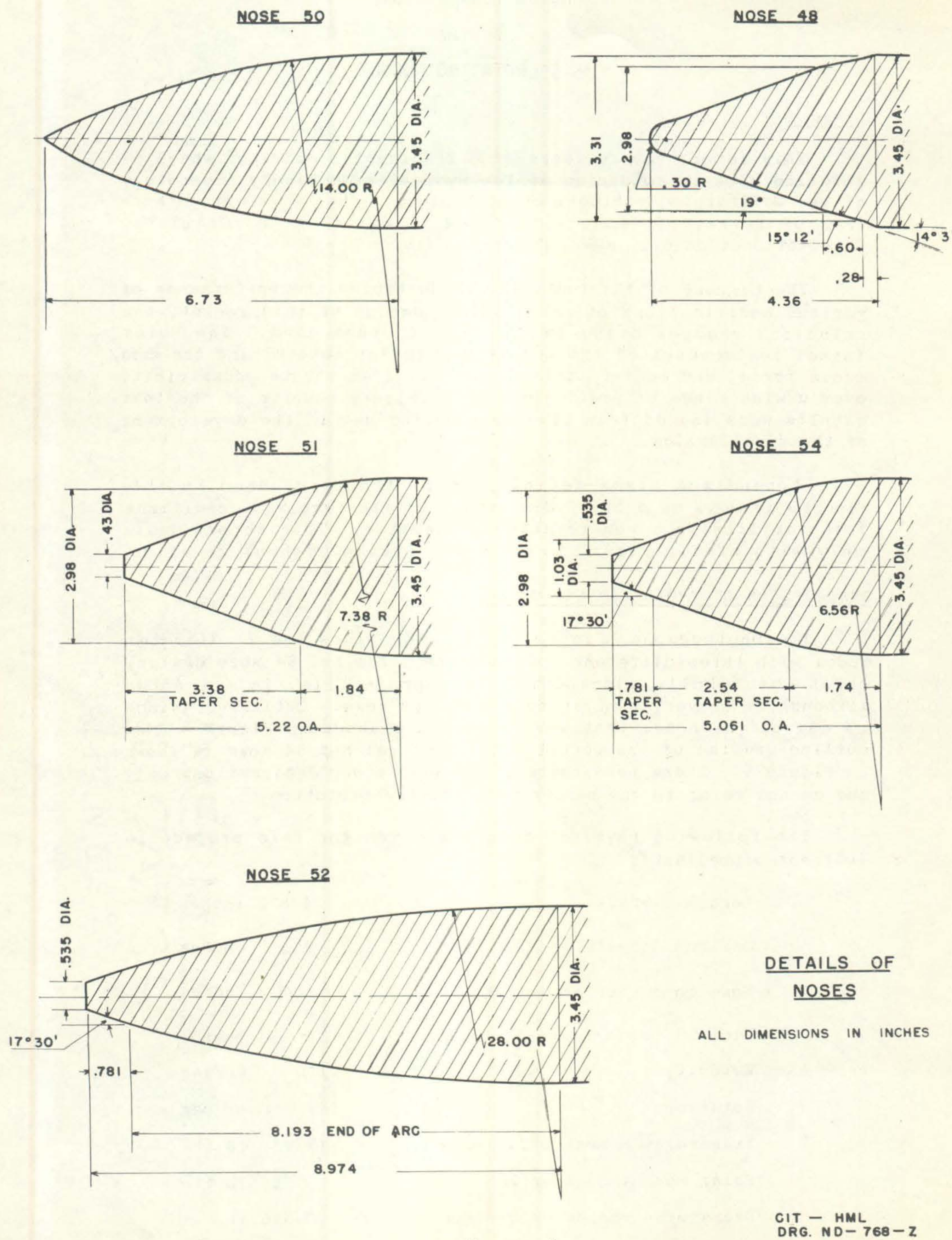
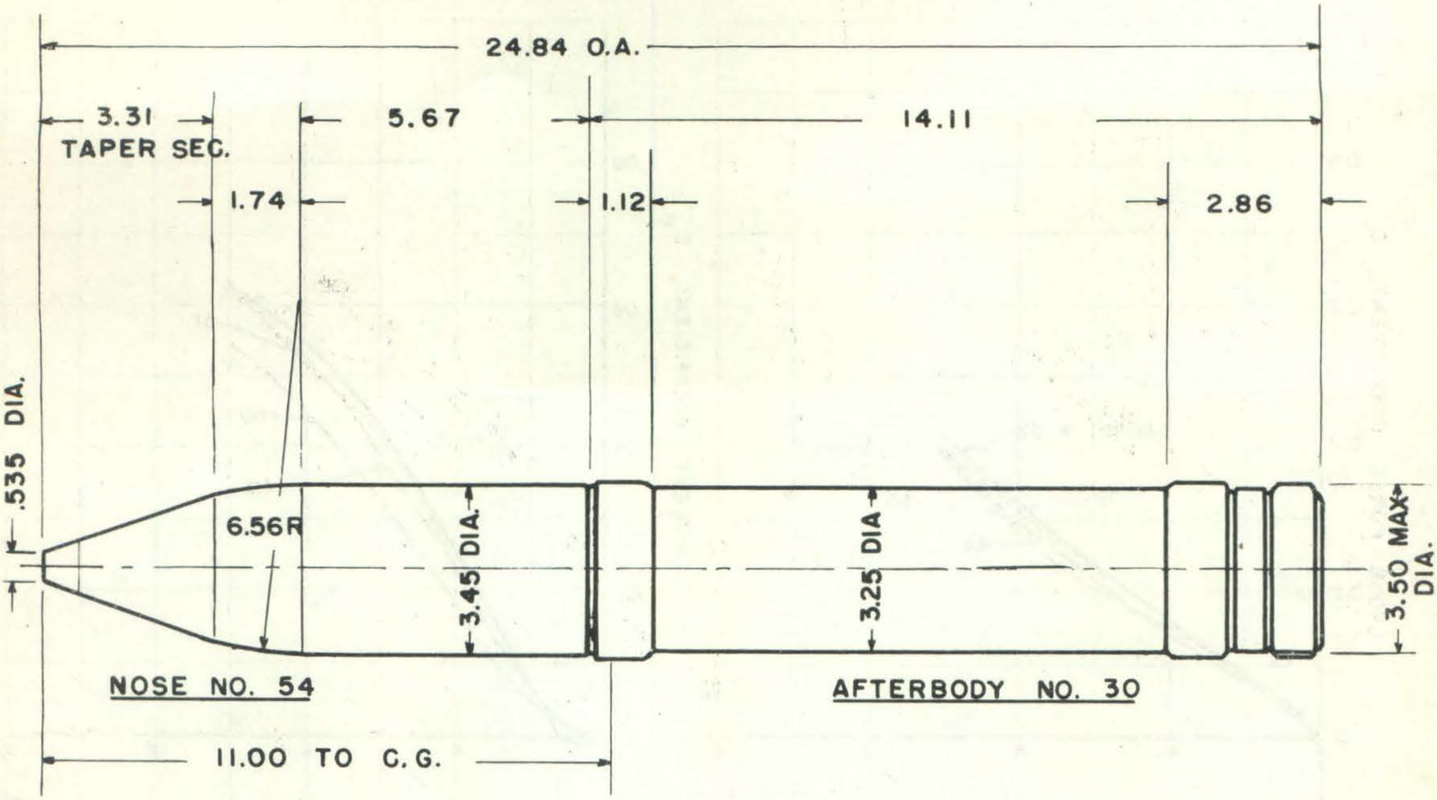

NOSE 50
3.45 DIA.
14.00 R
6.73
NOSE 48
3.31
2.98
.30 R
19°
15° 12'
.60
.28
4.36
3.45 DIA.
14° 3'
NOSE 51
2.98 DIA
.43 DIA
3.45 DIA.
7.38 R
3.38
TAPER SEC.
1.84
5.22 O.A.
NOSE 54
2.98 DIA
.535 DIA.
1.03 DIA.
17° 30'
6.56R
3.45 DIA.
.781
TAPER SEC.
2.54
TAPER SEC.
1.74
5.061 O. A.
NOSE 52
.535 DIA.
17° 30'
.781
28.00 R
3.45 DIA.
8.193 END OF ARC
8.974
DETAILS OF NOSES
ALL DIMENSIONS IN INCHES
CIT — HML
DRG. ND— 768—Z

FIGURE 4



OUTLINE OF PROTOTYPE

ALL DIMENSIONS IN INCHES

FIGURE 5

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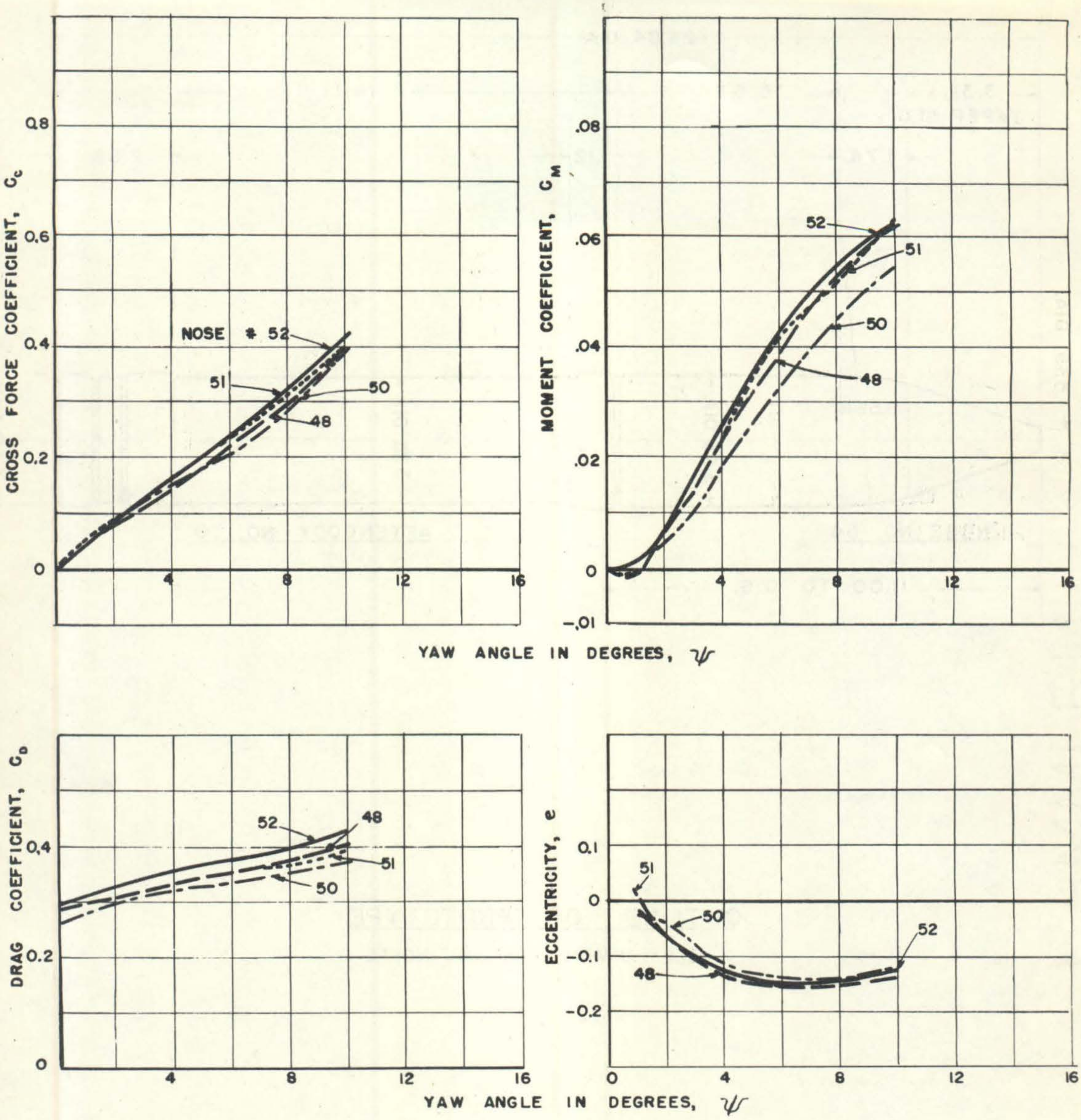


DRAG, CROSS FORCE AND MOMENT COEFFICIENTS AND C. P. ECCENTRICITY

3.5" ROTATING ROCKET WITH #48, #50, #51 & #52 NOSES

WATER VELOCITY 31.7 FT. PER SEC.

NOTE: CURVES ARE CORRECTED FOR SUPPORT INTERFERENCE

CIT — HML
ND 27 — 2839L

FIGURE 6

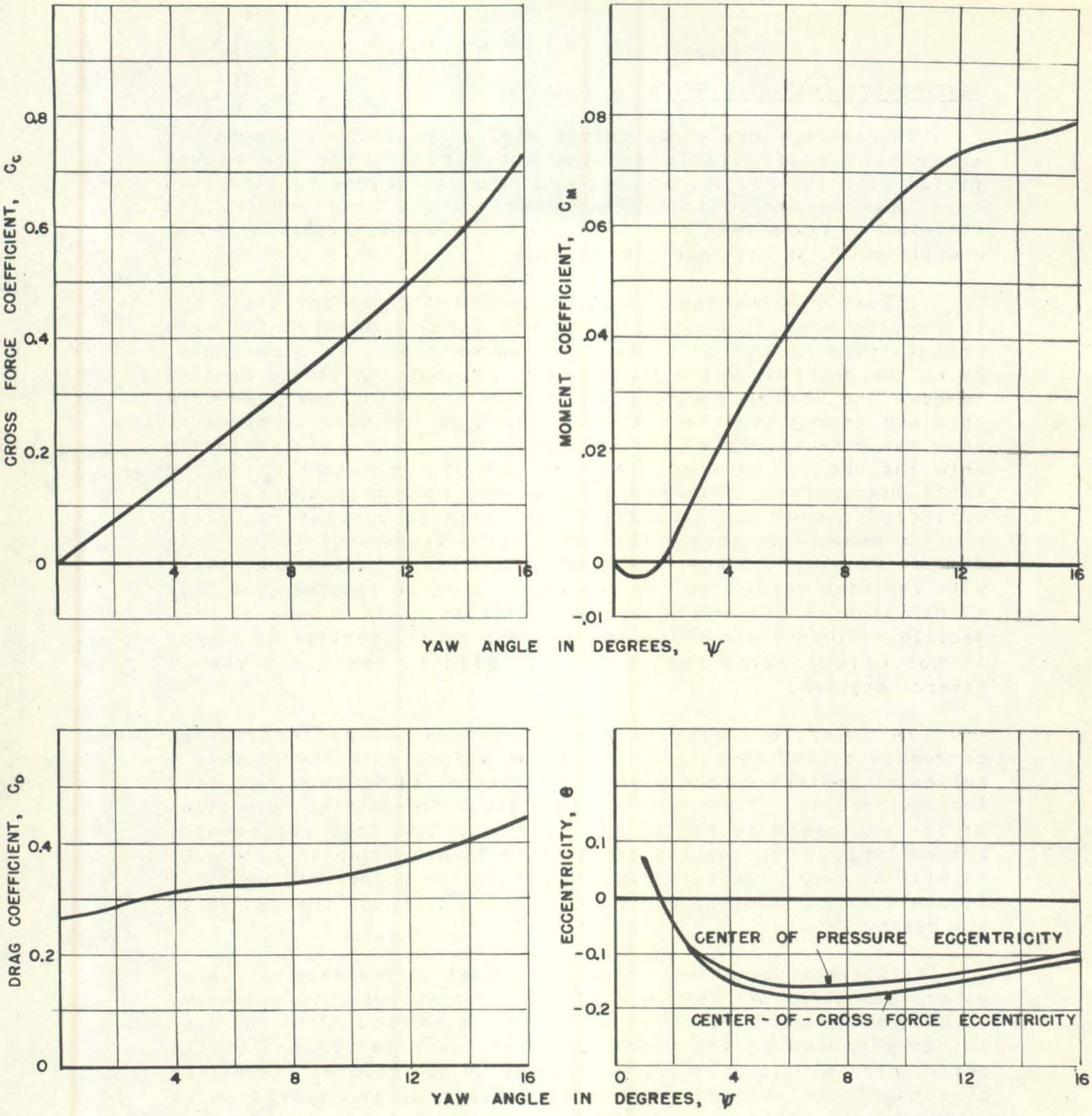
PERFORMANCE CHARACTERISTICS

In Figure 6 are shown curves giving the drag, cross force, and moment coefficients and the eccentricity for the rocket fitted with the No. 48, 50, 51, and 52 nose designs. All curves have been corrected for interference of the model supporting structure. It is seen that there is not a great variation in the coefficients for all four nose designs.

Figure 7 shows the coefficients and C.P. eccentricity for the No. 54 nose, the design that was finally adopted for this rocket. The center of cross force eccentricity is also shown, being the point at which the cross force, only should be applied to give the observed moment. Figure 8 gives the observed data obtained from a typical test run, which is included in order to show the consistency of the test results. It is interesting to note the decided reversal in curvature of the moment curve for small yaw angles. This reversal is even more pronounced in the corrected curves and indicates that there is a negative or restoring moment for yaws within one or two degrees of zero. This unexpected shape of the moment curve has been checked many times with the same result and the conclusion must be reached that this slight stabilizing moment is a peculiarity of this type of projectile. Field tests indicate that this small stabilizing moment is not effective as the rocket, in flight, assumes a yaw of several degrees.

In order to determine what variation in the coefficient curves is caused by varying the water velocity in the Tunnel, a series of tests was made with velocities of 14.9, 25.1, and 31.7 feet per second. These water velocities correspond to velocities of the prototype *in air* of 112, 189, and 238 feet per second, respectively. The results of these tests are given in Figure 9. As will be seen, there is some change in the values of the coefficients with different water velocities, although the change is not great.

An attempt was made to check the model performance at higher water velocities but the results were erratic owing to excessive vibration of the model. This vibration is attributed to the disturbance caused by the blunt afterbody, and is typical of the performance of all projectiles with blunt afterbodies travelling at subsonic velocities. It is probable that the vibration is caused by the alternating lateral forces which accompany the formation and detachment of the large scale vortices in the wake. It should be noted that these forces will act on the projectile in flight, and this may be expected to affect its performance.



DRAG, CROSS FORCE AND MOMENT COEFFICIENTS AND C. P. ECCENTRICITY

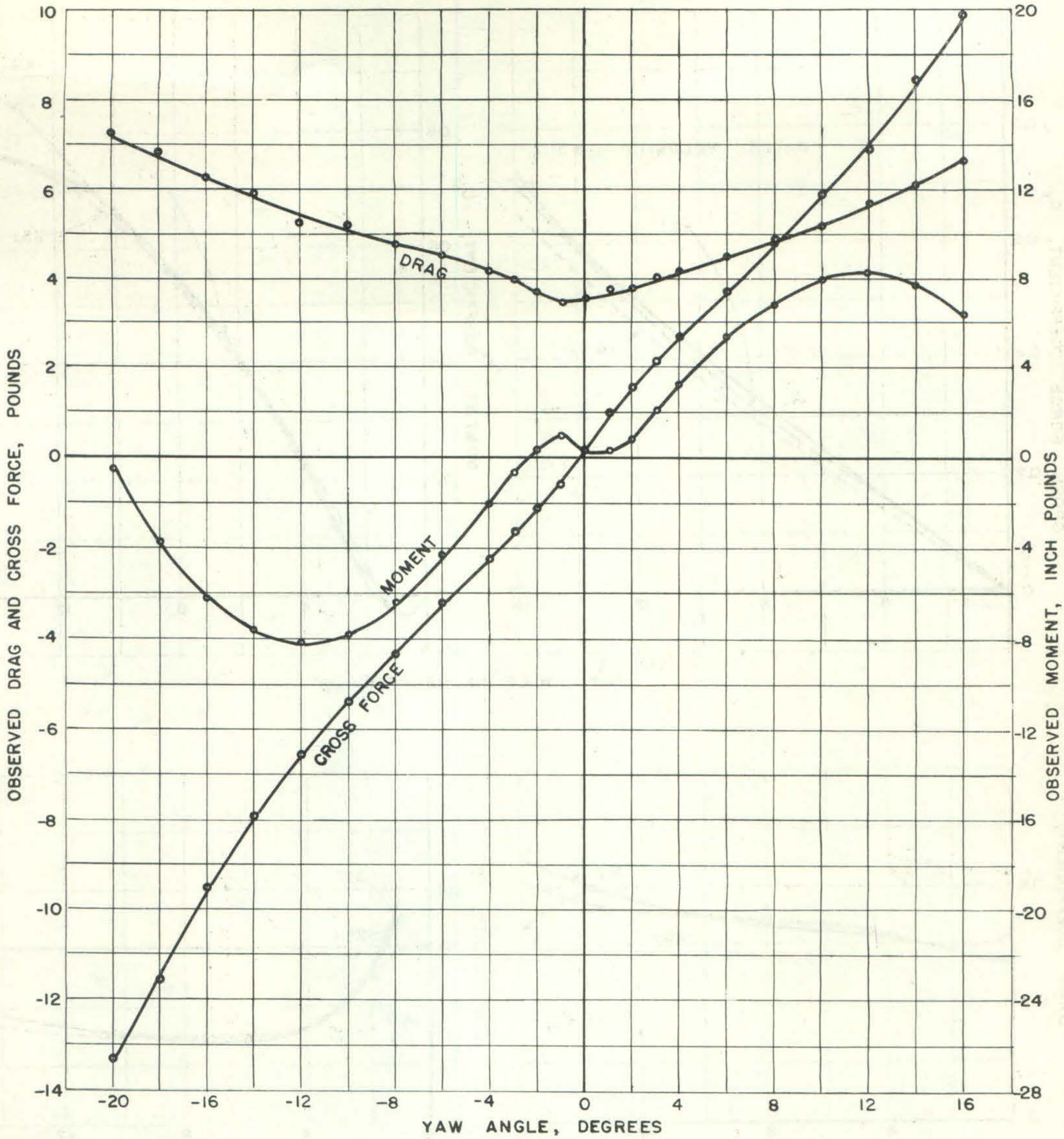
3.5" ROTATING ROCKET WITH # 54 NOSE

WATER VELOCITY 31.7 FT. PER SEC.

NOTE: CURVES ARE CORRECTED FOR SUPPORT INTERFERENCE

CIT - HML
ND 27-2837L

FIGURE 7

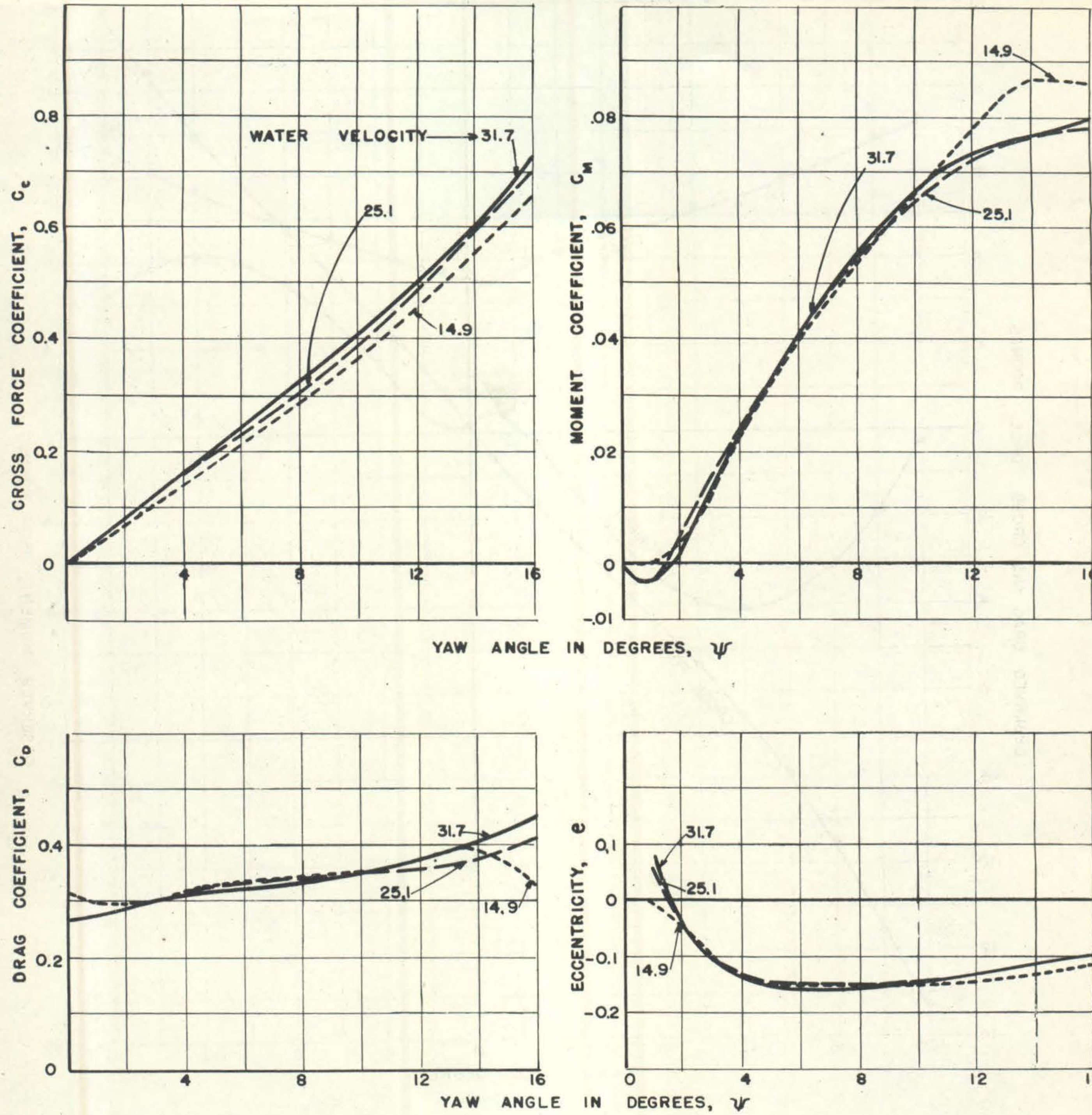


TYPICAL FORCE CURVES
(UNCORRECTED)

NOSE # 54

CIT — HML
ND 27 — 2841M

FIGURE 8



DRAG, CROSS FORCE AND MOMENT COEFFICIENTS AND C. P. ECCENTRICITY

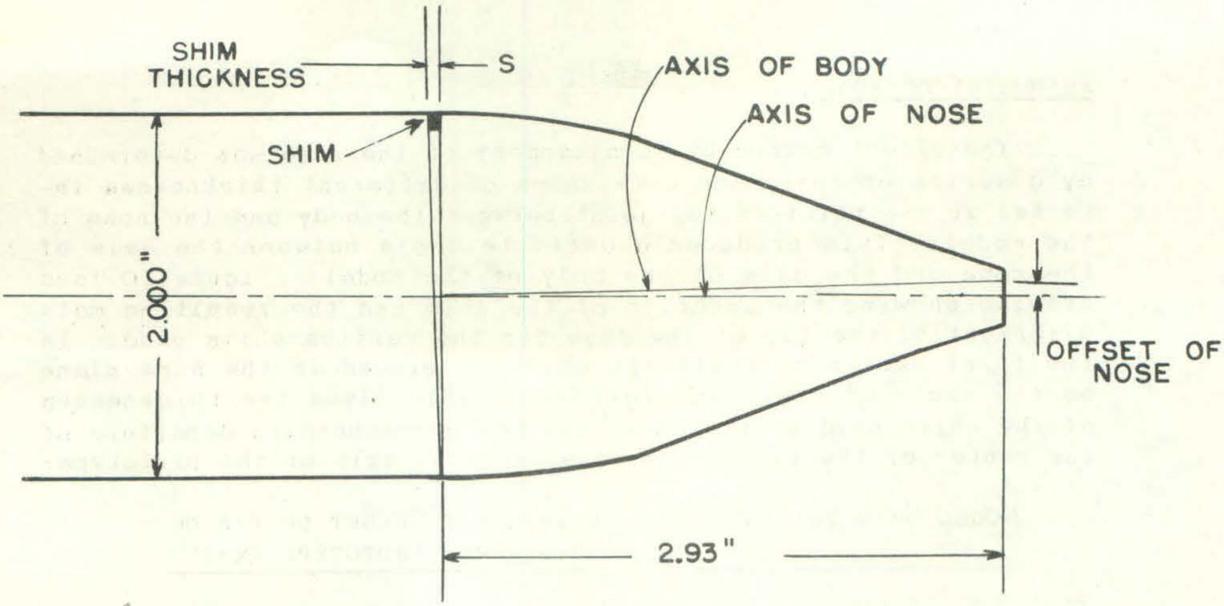
3.5" ROTATING ROCKET WITH # 54 NOSE

WATER VELOCITY 14.9, 25.1, & 31.7 FT/SEC.

NOTE: CURVES ARE CORRECTED FOR SUPPORT INTERFERENCE

CIT – HML
ND 27 – 2838 L

FIGURE 9



SHIM THICKNESS (MODEL)	OFFSET OF NOSE (MODEL)	CORRESPONDING OFFSET OF NOSE OF PROTOTYPE
.005 "	.007 "	.013 "
.010 "	.015 "	.025 "
.020 "	.029 "	.051 "
.050 "	.073 "	.130 "

SCALE RATIO $\frac{\text{PROTOTYPE}}{\text{MODEL}} = 1.725$

ASYMMETRY OF MODEL NOSE

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DRG. ND-766-T

FIGURE 10

ASYMMETRY OF NOSE

The effect caused by malalignment of the nose was determined by a series of runs made with shims of different thicknesses inserted at one point in the joint between the body and the nose of the model. This produced a definite angle between the axis of the nose and the axis of the body of the model. Figure 10 is a drawing showing the location of the shim and the resulting malalignment of the tip of the nose for the various shims used. In the first series of tests the shim was placed in the same plane as the angle of yaw. The following table gives the thicknesses of the shims used on the model and the corresponding departure of the center of the tip of the nose from the axis of the prototype.

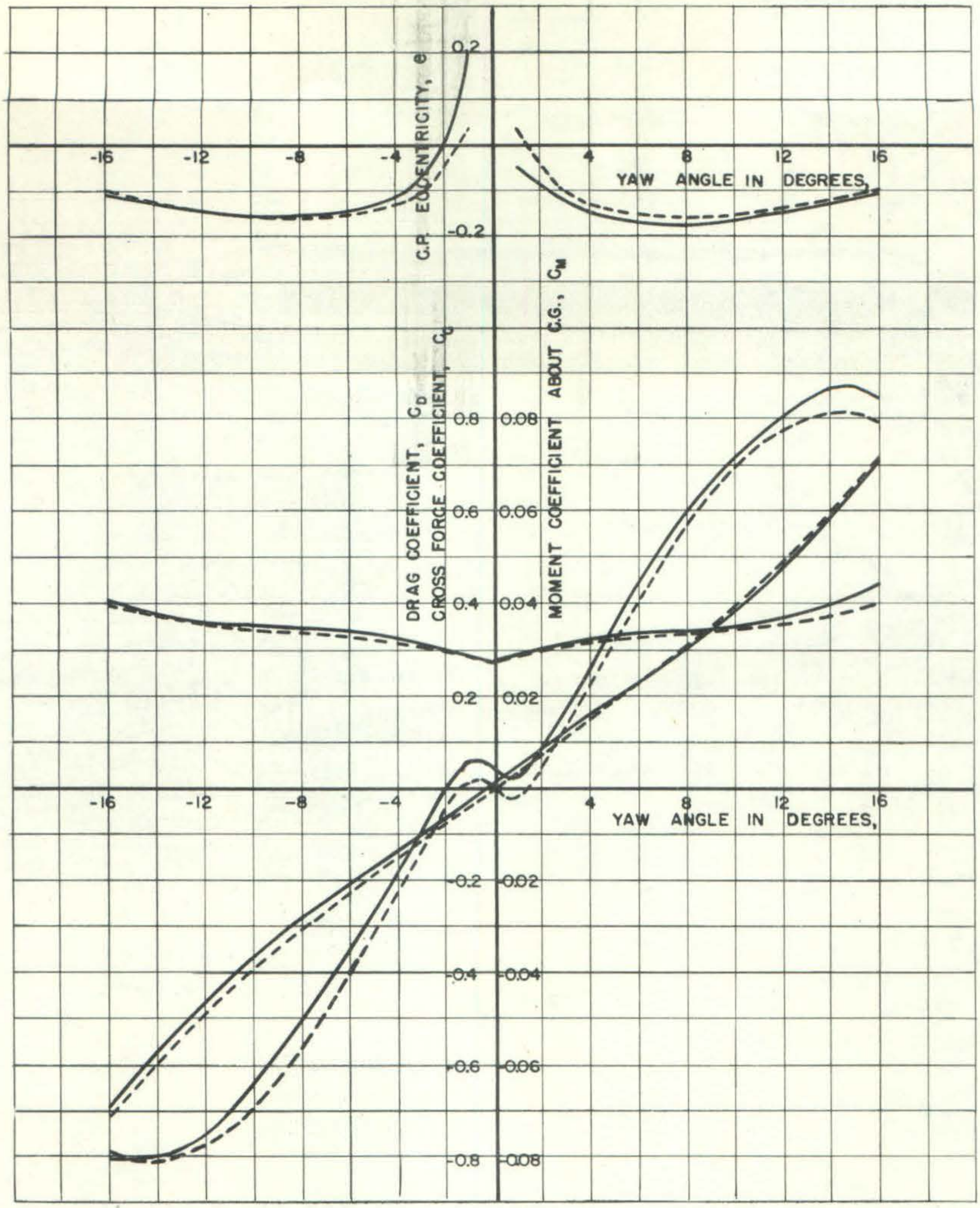
MODEL SHIM THICKNESS	EQUIVALENT OFFSET OF TIP OF NOSE FROM PROTOTYPE AXIS
0.005"	0.013"
0.010"	0.025"
0.020"	0.051"
0.050"	0.130"

As the 0.050" shim was the only one that produced any appreciable change in the coefficient curves, the data on the other shims have been omitted from this report. The 0.050" shim placed in the joint between the nose and the body of the model produced an offset of the center of the nose tip that would be equivalent to a little over 1/8" on the prototype. Under this condition the axis of the nose makes an angle of approximately $1\text{-}1/2^{\circ}$ with the axis of the body or, in other words, when the body has zero yaw the nose has a yaw of $+ 1\text{-}1/2^{\circ}$ which is in excess of the tolerances specified for this projectile.

Figure 11 shows the corrected coefficient curves for the rocket with and without this asymmetry of the nose. This asymmetry causes little change in the drag and cross force. The stabilizing moment is somewhat increased and is shifted to the region extending from 0° to $- 2^{\circ}$ yaw instead of extending between $- 1\text{-}1/2^{\circ}$ to $+ 1\text{-}1/2^{\circ}$ yaw, as with the symmetrical nose.

Figure 11 also clearly indicates that the asymmetry of the projectile results in asymmetrical performance curves, the nature of the asymmetry of the curves being what would be expected from the malalignment of the nose. The curves of C.P. eccentricity give the best indication of the effect produced by asymmetry of the projectile.

The changes in drag, cross force, and moment produced by this rather great asymmetry of the nose were unexpectedly small. It is, therefore, concluded that any asymmetry of the nose not exceeding the amount stated above would have no appreciable effect on the performance of the rocket.



---- ROCKET WITH SYMMETRICAL NOSE.

—— ROCKET WITH NOSE HAVING A YAW OF $+1\frac{1}{2}°$ WHEN AXIS OF ROCKET IS AT 0° YAW.

CURVES ARE CORRECTED FOR SUPPORT INTERFERENCE.

COEFFICIENT CURVES FOR
$3\frac{1}{2}$" ROTATING ROCKET
WITH AND WITHOUT ASYMMETRY
OF #54 NOSE

CIT — HML
ND 27 — 2840M

FIGURE 11

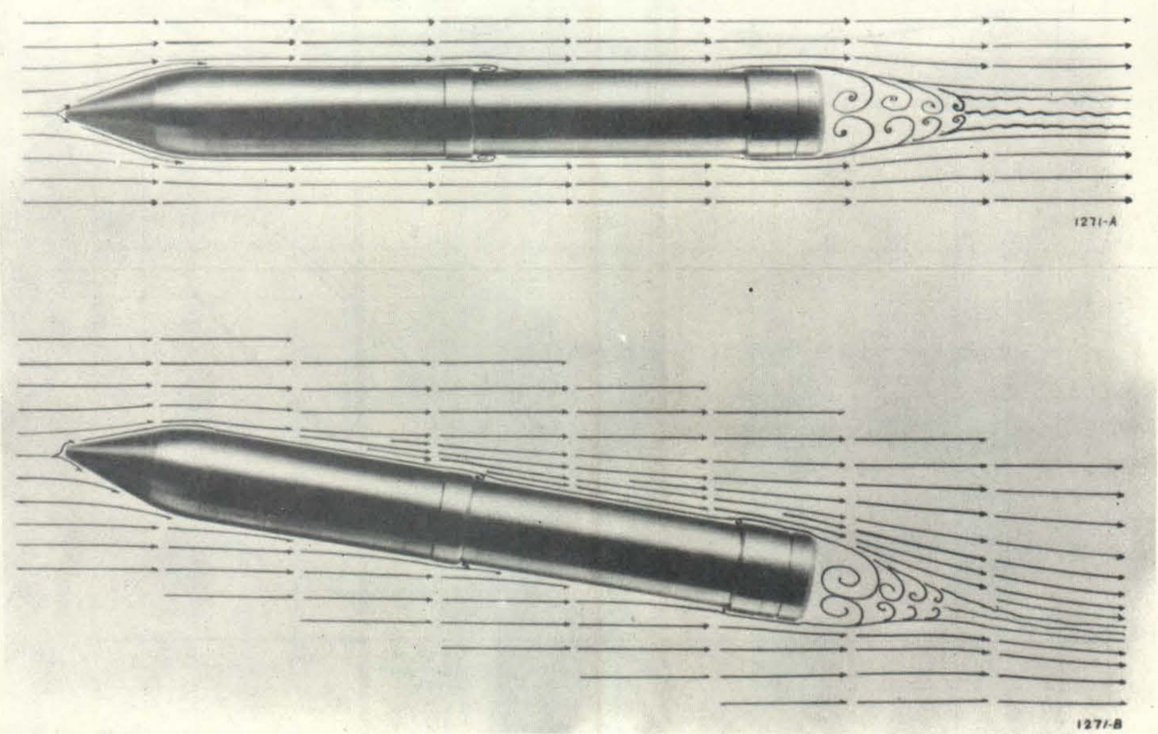


FIGURE 12

FLOW LINE DIAGRAMS WITH MODEL

AT 0° AND 10° YAW

Figure 12 shows the flow line diagrams for the model at 0° and 10° yaw. These diagrams were made from careful observations of the model in the Polarized Light Flume. In the above figure the model is shown with the No. 51 nose and these flow line diagrams are practically the same as those obtained with the other noses. It is apparent that the only appreciable disturbance is caused by the blunt end of the afterbody.

It is interesting to note that the 1/4" *decrease* in diameter near the center of the body causes some disturbance which does not occur at the point near the end where the diameter *increases* the same amount. This illustrates the fact that a projection into the flow will, in general, produce less disturbance in the flow pattern than will a similar step away from the flow.

THE HIGH SPEED WATER TUNNEL
AT THE
CALIFORNIA INSTITUTE OF TECHNOLOGY

APPENDIX A

DEFINITIONS

YAW ANGLE

The angle which the axis of the model makes with the direction of flow. Looking down on the model, yaw angles in a counter-clockwise direction are negative (-) and in a clockwise direction, positive (+).

MOMENTS

Moments tending to rotate the model in a counter-clockwise direction (when looking down on the model) are negative (-), and those causing clockwise rotation, positive (+).

In accordance with this sign convention a moment has a destabilizing effect when it has the same sign as the yaw angle.

In all model tests the moment is measured about the point of support.

Moments about the center of gravity have the symbol, M_{cg}.

DRAG

The force, in pounds, exerted on the model parallel with the direction of flow.

CROSS FORCE

The force, in pounds, exerted on the model normal to the direction of flow. A positive cross force is defined as one acting in the same direction as the displacement of the projectile nose for a positive yaw.

NORMAL COMPONENT

The sum of the components of the drag and cross force acting normal to the axis of the model. The value of the normal component is given by the following:

$$N = (D \sin \psi + C \cos \psi)$$

in which

N = Normal component in lbs

D = Drag in lbs

C = Cross force in lbs

ψ = Yaw angle in degrees

CENTER OF PRESSURE

The point in the axis of the model at which the resultant of all forces acting on the model is applied. This has the symbol (CP).

CENTER-OF-PRESSURE ECCENTRICITY

The distance between the center of pressure (CP) and the center of gravity (CG) expressed as a decimal fraction of the length (L) of the model. The center-of-pressure eccentricity (e) is derived as follows:

$$e = \frac{(L_{cp} - L_{cg})}{L} = \frac{1}{L} \quad \frac{M_{cg}}{N}$$

in which

e = Center-of-pressure eccentricity

L = Length of model in feet

L_{cg} = Distance from nose of projectile to CG in feet

L_{cp} = Distance from nose of projectile to CP in feet

COEFFICIENTS

The three force coefficients used are derived as follows:

Drag coefficient, $$C_D = \frac{D}{\rho \frac{V^2}{2} A_D}$$

Cross force coefficient, $$C_C = \frac{C}{\rho \frac{V^2}{2} A_D}$$

Moment Coefficient, $$C_M = \frac{M}{\rho \frac{V^2}{2} A_D L}$$

in which

D = Measured drag force in lbs

C = Measured cross force in lbs

ρ = Density of the fluid in slugs/cu ft

w = Specific weight of the fluid in lbs/cu ft

g = Acceleration of gravity in ft/sec^2

A_D = Area in sq ft of a cross section at the cylindrical portion of the projectile taken normal to the geometric axis of the projectile

V = Mean relative velocity between the water and the projectile in ft/sec

M = moment in foot-lbs measured about any particular point on the geometric axis of the projectile

L = overall length of the projectile in feet

GENERAL DISCUSSION

The curves of force and moment coefficients and of center-of-pressure distance plotted as functions of the yaw angle are useful for a discussion of the stability of projectiles. Since these tunnel tests are made under steady flow conditions, the results will only indicate the tendency of the projectile to return to or move away from the equilibrium position after a disturbance. Adopting aerodynamic usage, a projectile is said to be "statically" stable if it tends to return to equilibrium when disturbed. In the discussion of static stability the actual motion following the perturbation is not considered at all. In fact, a projectile may oscillate about the equilibrium position without ever remaining in it. In this case the projectile would be statically stable even though "dynamically" unstable. For a complete discussion of the mode of motion to be expected following a perturbation, the "dynamic" stability, additional information is necessary.

The condition for equilibrium is satisfied if C_M, calculated about the CG is equal to zero. In general, for projectiles with axial symmetry the moment is zero at $\psi = 0^{\circ}$, so that for equilibrium the projectile is oriented with its axis parallel to the direction of motion. If the projectile is rotated from the equilibrium position so as to give it a positive yaw angle, it is necessary that it have a negative moment coefficient, according to the sign convention adopted, in order that it be statically stable. Thus, a negative slope of the curve, C_M, vs. ψ corresponds to static stability, and a positive slope corresponds to instability. The degree of stability or instability is indicated by the magnitude of the slope. The same conclusions are obtained by interpreting the center-of-pressure curves. For symmetrical projectiles, if the center of pressure falls behind the center of gravity, a restoring moment exists and the projectile is statically stable. If the CP lies ahead of the CG, the moment is non-restoring and the projectile is statically unstable. The degree of stability or instability is indicated by the distance between the center of gravity and center of pressure.